

# Mucool-Cryostat design-thermal loads to the LH2 absorber calculation

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## 1. Purpose and assumptions

### Geometry

- we have considered:
  - Magnet (Al)
  - the Vacuum Vessel (Stainless Steel)
  - the Thermal Shield (Al)
  - Absorber manifold (Stainless Steel) (conservative emissivity)
- There is a Multi-Layer-Insulation (of **30 layers**) on the Thermal Shield.
- (There is a Multi-Layer-Insulation (of **1 layers**) on the Absorber )

### Emissivity

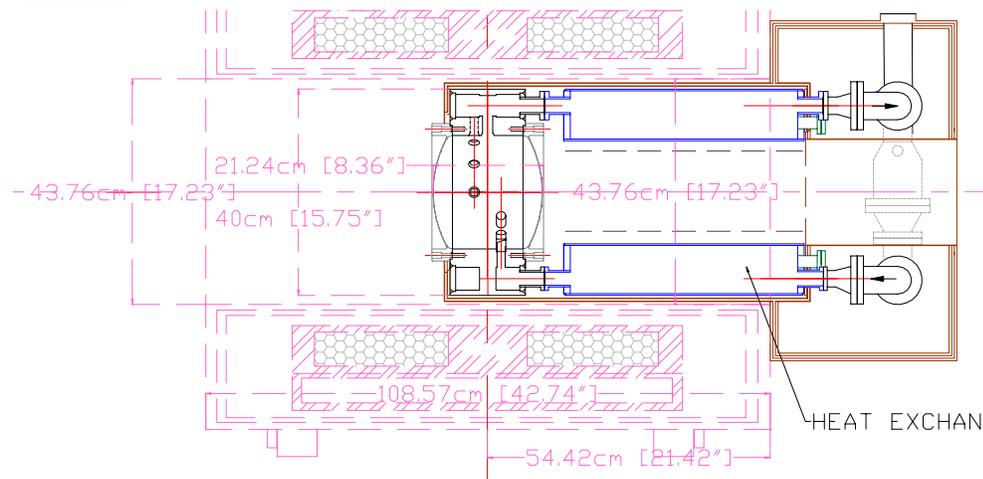
- the Emissivity of the different materials, are linearly interpolated thanks to data from [2]
- the Emissivity from Aluminium is Al mechanically bluffed/ TS
- The a and b coefficient for the heat transfer throught the MLI are issued from CERN experiments. The (a,b) are given for different vacuum insulation pressure degradations:  $10^{-6}$  mbar,  $10^{-3}$ mbar and  $10^{-2}$  mbar)

### Formula (cf notations):

- VV to TS : conduction through superinsulation (a,b)
- TS to Absorber: conduction through superinsulation (a,b) and test for one layer (emissivity of Aluminized Mylar)
- ...

## GENERALISATION

#\_scheme



### #\_Notations:

T: temperature  
t: temps

CM: Cold Mass : Stainless Steel

MLI: Multi-Layer-Insulation : Mylar polyester film and spacers

TS: Thermal Shield : Aluminium (mechanically bluffed [2])

VV: Vacuum Vessel : Stainless Steel

Mag: Lab-G Magnet (inner diameter) : Aluminum

## 2. DATA

### # Temperatures:

$T_{mag} := 300 \cdot K$	: Temperature at the cold mass		
$T_{vv} := 300 \cdot K$	: Temperature at the RS		
$T_{ts} := 80 \cdot K$	: Temperature between Tts and Alu Braid	$T_{tsin} := 77 \cdot K$	$T_{tsout} := 80 \cdot K$
$T_{abs} := 20 \cdot K$	: Temperature of the absorber		

$PV := 10^{-6}$  : Vacuum Pression [mbar]

$C_p := 2.05 \cdot 10^3 \cdot \frac{joule}{kg \cdot K}$  : CP Nitrogen

### Lengths:

### Diameters

$L_{mag} := 43 \cdot in$	$Dimag := 17.32 \cdot in$		
$L_{abs} := L_{mag}$	$Doabs := 13.52 \cdot in$		
$L_{HX} := 20 \cdot in$	$L_{absseul} := 8.46 \cdot in$	$D_{HX} := 5 \cdot in$	
$L_{VV} := L_{mag}$		$DoVV := 16 \cdot in$	
		$DiVV := 15.62 \cdot in$	
$L_{TS} := L_{VV}$			
$L_{externalVV} := L_{HX}$	$DiTS := DoTS - 2 \cdot 1.5 \cdot cm$	$DiTS := Doabs + \frac{(DiVV - Doabs)}{2}$	$DiTS = 0.37 \text{ m}$
	$d_{TLo} := 0.84 \cdot in$	$DoTS := DiTS + 2 \cdot 1.5 \cdot mm$	
	$d_{TLi} := 0.71 \cdot in$		
	$d_{pump} := 6 \cdot in$		

### Surfaces

$Surfmag := L_{mag} \cdot \pi \cdot Dimag$		$Surfmag = 1.51 \text{ m}^2$
$SurfHX := L_{HX} \cdot \pi \cdot D_{HX}$		$SurfHX = 0.203 \text{ m}^2$
$Surf_{abs} := L_{abs} \cdot \pi \cdot Doabs + L_{mag} \cdot 3.14 \cdot d_{TLo} + L_{HX} \cdot 3.14 \cdot d_{pump}$		$Surf_{abs} = 1.495 \text{ m}^2$
$SurfoVV := L_{VV} \cdot \pi \cdot DoVV$		$SurfoVV = 1.394 \text{ m}^2$
$SurfiVV := L_{VV} \cdot \pi \cdot DiVV + 3.14 \cdot DiVV \cdot L_{externalVV}$		$SurfiVV = 1.994 \text{ m}^2$
$SurfoTS := L_{TS} \cdot \pi \cdot DoTS$		$SurfoTS = 1.28 \text{ m}^2$
$SurfiTS := L_{TS} \cdot \pi \cdot DiTS$		
$L_{contactmag\_VV} := \frac{L_{VV}}{10}$	$contactmag\_VV := 3 \cdot 0.5 \cdot in$ $L_{contactmag\_VV} = 4.3 \text{ in}$	$Surf_{contactmag\_VV} := L_{contactmag\_VV} \cdot contactmag\_VV$ $Surf_{contactmag\_VV} = 0.004 \text{ m}^2$
$L_{contactVV\_ts} := \frac{L_{VV}}{10}$	$contactVV\_ts := 3 \cdot 1 \cdot in$ $L_{contactVV\_ts} = 4.3 \text{ in}$	$Surf_{contactVV\_ts} := L_{contactVV\_ts} \cdot contactVV\_ts$ $Surf_{contactVV\_ts} = 0.008 \text{ m}^2$
$L_{contactts\_abs} := 2 \cdot 0.75 \cdot in$	$contactts\_abs := 3 \cdot 1 \cdot in$ $L_{contactts\_abs} = 1.5 \text{ in}$	$Surf_{contactts\_abs} := L_{contactts\_abs} \cdot contactts\_abs$ $Surf_{contactts\_abs} = 0.003 \text{ m}^2$

$$\text{Surfcontact\_abs} := \frac{\pi}{4} \cdot (d_{\text{TLo}}^2 - d_{\text{TLi}}^2) \quad \text{PerteTS\_CTMadapt\_cm11.mcd}$$

$$\text{Surfabsper} := \frac{\pi}{4} \cdot (\text{Doabs}^2)$$

$$\text{SurfiVVper} := \frac{\text{LVV} \cdot 3.14 \cdot \text{DiTS}}{2}$$

$$\text{Surfcontact abs} = 1.021 \times 10^{-4} \text{ m}^2$$

$$\text{Surfabsper} = 0.093 \text{ m}^2$$

$$\text{SurfiVVper} = 0.635 \text{ m}^2$$

### Thermal lengths

$$\text{Lmag\_VV} := \frac{(\text{Dimag} - \text{DoVV})}{2}$$

$$\text{Lmag\_VV} = 0.66 \text{ in}$$

$$\text{Dimag} = 0.44 \text{ m}$$

$$\text{DoVV} = 0.406 \text{ m}$$

$$\text{LVV\_ts} := 0.66 \cdot \text{in}$$

$$\text{LVV\_ts} = 0.017 \text{ m}$$

$$\text{DiVV} = 0.397 \text{ m}$$

$$\text{Lts\_abs} := 0.33 \cdot \text{in}$$

$$\text{Lts\_abs} = 0.838 \text{ cm}$$

$$\text{DoTS} = 0.373 \text{ m}$$

$$\text{L\_abs} := (\text{LVV} - \text{Labsseul})$$

$$\text{L\_abs} = 0.877 \text{ m}$$

$$\text{DiTS} = 0.37 \text{ m}$$

$$\text{Doabs} = 0.343 \text{ m}$$

$$\text{LTL} := 20.56 \cdot \text{in}$$

### # Constantes:

$$\sigma := 5.67 \cdot (10^{-8}) \cdot \frac{\text{watt}}{\text{m}^2 \cdot \text{K}^4} \quad : \text{ Stefan-Boltzmann's constant} \quad [\text{Wm}^{-2}\text{K}^{-4}]$$

### # Conductivity of G10 and stainless steel (spider between the magnet and the Vacuum vessel)

$$\text{Temp} := \begin{pmatrix} 1.8 \\ 3 \\ 5 \\ 7 \\ 10 \\ 20 \\ 30 \\ 50 \\ 100 \\ 200 \\ 293 \end{pmatrix} \cdot \text{K} \quad \text{kG10} := \begin{pmatrix} .035 \\ .059 \\ .090 \\ .120 \\ .150 \\ .190 \\ .24 \\ .29 \\ .43 \\ .65 \\ .8 \end{pmatrix} \cdot \frac{\text{watt}}{\text{K} \cdot \text{m}}$$

$$\text{Tss} := \begin{pmatrix} 4 \\ 6 \\ 8 \\ 10 \\ 15 \\ 20 \\ 25 \\ 30 \\ 35 \\ 40 \\ 50 \\ 60 \\ 70 \\ 80 \\ 90 \\ 100 \\ 120 \\ 140 \\ 160 \\ 180 \\ 200 \\ 250 \\ 300 \end{pmatrix} \cdot \text{K} \quad \text{SS} := \begin{pmatrix} 0.24 \\ 0.39 \\ 0.57 \\ 0.77 \\ 1.32 \\ 1.95 \\ 2.6 \\ 3.3 \\ 4.0 \\ 4.7 \\ 5.8 \\ 6.8 \\ 7.6 \\ 8.3 \\ 9.0 \\ 9.5 \\ 10.3 \\ 11.0 \\ 12.0 \\ 12.3 \\ 13.0 \\ 14.0 \\ 15.0 \end{pmatrix} \cdot \frac{\text{watt}}{\text{K} \cdot \text{m}}$$

$$\text{kk1G10(T)} := \text{linterp}(\text{Temp}, \text{kG10}, \text{T}) \quad \text{kSS(T)} := \text{linterp}(\text{Tss}, \text{SS}, \text{T})$$

$$\text{Kcontactmag\_VV} := \int_{\text{Tvv}}^{\text{Tmag}} \text{kk1G10(T)} \, dT \quad \text{Kcontactmag\_VV} = 0 \text{ m}^{-1} \text{ watt}$$

$$\text{KcontactVV\_ts} := \int_{\text{Tts}}^{\text{Tvv}} \text{kk1G10(T)} \, dT \quad \text{KcontactVV\_ts} = 135.103 \text{ m}^{-1} \text{ watt}$$

$$\text{Kcontactts\_abs} := \int_{\text{Tabs}}^{\text{Tts}} \text{kk1G10(T)} \, dT \quad \text{Kcontactts\_abs} = 17.41 \text{ m}^{-1} \text{ watt}$$

$$\text{Kcontact\_abs} := \int_{\text{Tabs}}^{\text{Tmag}} \text{kSS(T)} \, dT \quad \text{Kcontact\_abs} = 3049.583 \text{ m}^{-1} \text{ watt}$$

## # Emissivity:

PerteTS\_CTMadapt\_cm11.mcd

### 1. Aluminium (bluffed mechanically)

$$TAI := \begin{pmatrix} 4 \\ 80 \cdot K \\ 300 \end{pmatrix} \quad [2], p42 \quad EAI := \begin{pmatrix} 0.06 \\ 0.1 \\ 0.2 \end{pmatrix}$$

$$eAl(t) := \text{linterp}(TAI, EAI, t)$$

### material brut

$$EAlbrut := \begin{pmatrix} 0.07 \\ 0.12 \\ 0.25 \end{pmatrix}$$

$$eAlbrut(t) := \text{linterp}(TAI, EAlbrut, t)$$

### 2. Copper poli électrolitiquement

$$T := \begin{pmatrix} 4 \\ 77 \cdot K \\ 300 \end{pmatrix} \quad Ecopper := \begin{pmatrix} 0.02 \\ 0.06 \\ 0.1 \end{pmatrix}$$

$$ecopper(t) := \text{linterp}(T, Ecopper, t)$$

### 3. STAINLESS STEEL

$$ESS := \begin{pmatrix} 0.1 \\ 0.15 \\ 0.2 \end{pmatrix}$$

$$eSS(t) := \text{linterp}(T, ESS, t)$$

## # Emissivity from magnet to vv

$$Emag\_vv(Tc, Tf) := \frac{1}{\left[ \frac{1}{eAlbrut(Tc)} + \frac{\text{SurfoVV} \cdot \left( \frac{1}{eSS(Tf)} - 1 \right)}{\text{Surfmag}} \right]}$$

$$Emag\_vv := Emag\_vv(Tmag, Tvv) \quad Emag\_vv = 0.13$$

## # Emissivity to absorber

$$E\_abs(Tc, Tf) := \frac{1}{\left[ \frac{1}{eSS(Tc)} + \frac{\text{Surfabsp} \cdot \left( \frac{1}{1} - 1 \right)}{\text{SurfiVVper}} \right]}$$

$$E\_abs := E\_abs(Tvv, Tabs) \quad E\_abs = 0.2$$

$$\text{Surfabsp} = 0.093 \text{ m}^2 \\ \text{SurfiVVper} = 0.635 \text{ m}^2$$

## # Mylar emissivity (analogy with electrolytically bluffed Aluminium) [2: Tech. ing.], p42

$$TMyl := \begin{pmatrix} 4 \\ 80 \cdot K \\ 300 \end{pmatrix} \quad EMyl := \begin{pmatrix} 0.04 \\ 0.08 \\ 0.15 \end{pmatrix}$$

$$eMyl(t) := \text{linterp}(TMyl, EMyl, t)$$

$$Evv\_tsMyl(Tc, Tf) := \frac{1}{\left[ \frac{1}{eMyl(Tf)} + \frac{\text{SurfoTS} \cdot \left( \frac{1}{eSS(Tc)} - 1 \right)}{\text{SurfiVV}} \right]}$$

$$Evv\_tsMyl := Evv\_tsMyl(Tvv, Tts) \quad Evv\_tsMyl = 0.066$$

$$Ets\_abs(Tc, Tf) := \frac{1}{\left[ \frac{1}{eSS(Tf)} + \frac{\text{Surfabs} \cdot \left( \frac{1}{eAlbrut(Tc)} - 1 \right)}{\text{SurfiTS}} \right]}$$

$$Ets\_abs := Ets\_abs(Tts, Tabs) \quad Ets\_abs = 0.057$$

## # Conduction in residual gas though MLI

Data [forminsul.mcd]:

PerteTS\_CTMadapt\_cm11.mcd

There are N10 := 10 layers of MLI on the RS

Tmag = 300 K

There are N30 := 30 layers of MLI on the TS

Tvv = 300 K

Tts = 80 K

Tab = 20 K

$$Q_{vv\_ts}(a, b, A) := \left[ \frac{a}{N30} \cdot \left( \frac{T_{vv}^2 - T_{ts}^2}{2} \right) + \frac{b}{N30} \cdot (T_{vv}^4 - T_{ts}^4) \right] \cdot A$$

$$Q_{ts\_abs}(a, b, A) := \left[ \frac{a}{N10} \cdot \left( \frac{T_{ts}^2 - T_{abs}^2}{2} \right) + \frac{b}{N10} \cdot (T_{ts}^4 - T_{abs}^4) \right] \cdot A$$

Calculations of a and b for different pressures:

1E-6 bar	$a_6 := 1.4 \cdot 10^{-4} \cdot \frac{\text{watt}}{\text{m}^2 \cdot \text{K}^2}$	$b_6 := 3.74 \cdot 10^{-9} \cdot \frac{\text{watt}}{\text{m}^2 \cdot \text{K}^4}$
1E-3 bar	$a_3 := 6.544 \cdot 10^{-3} \cdot \frac{\text{watt}}{\text{m}^2 \cdot \text{K}^2}$	$b_3 := -2.166 \cdot 10^{-8} \cdot \frac{\text{watt}}{\text{m}^2 \cdot \text{K}^4}$
1E-2 bar	$a_2 := 0.05 \cdot \frac{\text{watt}}{\text{m}^2 \cdot \text{K}^2}$	$b_2 := -2.212 \cdot 10^{-7} \cdot \frac{\text{watt}}{\text{m}^2 \cdot \text{K}^4}$

## 3. CALCULATIONS

### 3.1 RADIATION AND CONDUCTION FROM WARM MAGNET TO VV

$$Q_{\text{mag\_VVrad}} := \text{Emag\_vv} \cdot \sigma \cdot (T_{\text{mag}}^4 - T_{\text{vv}}^4) \cdot \text{SurfoVV}$$

$$Q_{\text{mag\_VVrad}} = 0 \text{ watt}$$

$$Q_{\text{mag\_VVcond}} := K_{\text{contactmag\_VV}} \cdot \frac{\text{Surfcontactmag\_VV}}{L_{\text{mag\_VV}}}$$

$$Q_{\text{mag\_VVcond}} = 0 \text{ watt}$$

$$Q_{\text{mag\_VV}} := Q_{\text{mag\_VVrad}} + Q_{\text{mag\_VVcond}}$$

$$Q_{\text{mag\_VV}} = 0 \text{ watt}$$

>> reduction of the contact area btw magn and VV

### 3.2 RADIATION AND CONDUCTION FROM VV to TS

Pressure : 1E-6 mbar

a. Between VV and TS

$$W_{6vv\_tsMyl} := \text{E}_{vv\_tsMyl} \cdot \sigma \cdot \text{SurfoTS} \cdot (T_{vv}^4 - T_{ts}^4)$$

$$W_{6vv\_tsMyl} = 38.821 \text{ watt} \quad \text{With no MLI}$$

$$W_{6vv\_tsMLI} := Q_{vv\_ts}(a_6, b_6, \text{SurfoTS})$$

$$W_{6vv\_tsMLI} = 1.536 \text{ watt} \quad \text{With MLI}$$

Pressure : 1E-3 mbar

a. Between VV and TS

$$W_{3vv\_tsMLI} := Q_{vv\_ts}(a_3, b_3, \text{SurfoTS})$$

$$W_{3vv\_tsMLI} = 4.224 \text{ watt} \quad \text{With MLI}$$

Pressure : 1E-2 mbar

a. Between VV and TS

$$W_{2vv\_tsMLI} := Q_{vv\_ts}(a_2, b_2, \text{SurfoTS})$$

$$W_{2vv\_tsMLI} = 13.114 \text{ watt} \quad \text{With MLI}$$

## # Conduction

$$Q_{con\_vv\_ts} := K_{contactVV\_ts} \cdot \frac{SurfcontactVV\_ts}{L_{VV\_ts}}$$

$$L_{VV\_ts} = 0.017 \text{ m} \quad L_{contactVV\_ts} = 0.109 \text{ m}$$

$$SurfcontactVV\_ts = 0.008 \text{ m}^2 \quad K_{contactVV\_ts} = 135.103 \text{ m}^{-1} \text{ watt}$$

$$PerteTS \text{ CTMadapt\_cm11.mcd}$$

$$Q_{con\_vv\_ts} = 67.073 \text{ watt}$$

## # Total heat to the TS (to be extracted by N2 cooling lines)

$$Q_{vv\_tsnoMLI} := W_{6vv\_tsMyl} + Q_{con\_vv\_ts}$$

$$Q_{vv\_ts} := W_{6vv\_tsMLI} + Q_{con\_vv\_ts}$$

$$Q_{vv\_tsnoMLI} = 105.894 \text{ watt}$$

$$Q_{vv\_ts} = 68.608 \text{ watt}$$

## 3.3 RADIATION AND CONDUCTION FROM TS to Absorber

Pressure : 1E-6 mbar

b. Between TS and Abs  $Surf_{abs} := Surf_{abs} + 4 \cdot 1 \cdot in \cdot LTL \cdot 3.14$

$$W_{6ts\_absMyl} := E_{ts\_abs} \cdot \sigma \cdot Surf_{abs} \cdot (T_{ts}^4 - T_{abs}^4)$$

$$W_{6ts\_absMyl} = 0.218 \text{ watt}$$

With no MLI

$$W_{6ts\_absMLI} := Q_{ts\_abs}(a6, b6, Surf_{abs})$$

$$W_{6ts\_absMLI} = 0.095 \text{ watt}$$

With MLI

Pressure : 1E-3 mbar

b. Between TS and Abs

$$W_{3ts\_absMLI} := Q_{ts\_abs}(a3, b3, Surf_{abs})$$

$$W_{3ts\_absMLI} = 3.114 \text{ watt}$$

With MLI

Pressure : 1E-2 mbar

b. Between TS and Abs

$$W_{2ts\_absMLI} := Q_{ts\_abs}(a2, b2, Surf_{abs})$$

$$W_{2ts\_absMLI} = 23.419 \text{ watt}$$

With MLI

## # Radiation from the two containment windows @RT

$$Q_{extremity\_abs} := E_{abs} \cdot \sigma \cdot Surf_{absper} \cdot (T_{vv}^4 - T_{abs}^4)$$

$$Q_{extremity\_abs} = 8.507 \text{ watt}$$

$$(=35 \text{ Watt if } E_{abs}=1)$$

## # Conduction

$$Q_{cond\_abs} := K_{contact\_abs} \cdot \frac{Surf_{contact\_abs}}{L_{abs}}$$

$$Q_{cond\_abs} = 0.355 \text{ watt}$$

$$L_{abs} = 0.877 \text{ m}$$

$$Q_{condts\_abs} := K_{contactts\_abs} \cdot \frac{Surf_{contactts\_abs}}{L_{ts\_abs}}$$

$$Q_{condts\_abs} = 6.03 \text{ watt}$$

## # Total heat to the absorber

$$Q_{condts\_abs} := K_{contactts\_abs} \cdot \frac{Surf_{contactts\_abs}}{L_{ts\_abs}}$$

$$Q_{ts\_abs} := W_{6ts\_absMyl} + 2 \cdot Q_{extremity\_abs} + Q_{condts\_abs} + 2 \cdot Q_{cond\_abs}$$

$$Q_{ts\_abs} = 23.973 \text{ watt}$$

$$Safetyfactor := 2$$

$$Q_{abs} := Q_{ts\_abs} \cdot Safetyfactor$$

$$W_{6ts\_absMyl} = 0.218 \text{ watt}$$

$$Q_{extremity\_abs} = 8.507 \text{ watt}$$

$$Q_{condts\_abs} = 6.03 \text{ watt}$$

$$Q_{cond\_abs} = 0.355 \text{ watt}$$

$$Q_{abs} = 47.945 \text{ watt}$$

### 3.4. Mass flow calculation for the TS cooling tubes

PerteTS\_CTMadapt\_cm11.mcd

$$mLN2 := 199 \cdot 10^3 \cdot \frac{\text{joule}}{\text{kg}}$$

$$Q_{vv\_ts} = 68.608 \text{ watt}$$

$$T_{tsout} = 80 \text{ K}$$

$$Do_{abs} = 13.52 \text{ in}$$

$$T_{tsin} = 77 \text{ K}$$

$$\text{mass\_flowTS} := \frac{Q_{vv\_ts}}{[C_p \cdot (T_{tsout} - T_{tsin})]}$$

$$Q_{vv\_ts} = 68.608 \text{ watt}$$

$$\text{mass\_flowTS} = 11.156 \cdot 10^{-3} \cdot \frac{\text{kg}}{\text{sec}}$$

$$\text{mass\_flowTS} := \frac{Q_{vv\_ts}}{(mLN2)}$$

### 4. Summary of the heat loads

#### To the TS- MLI, good vacuum:

$$W_{6vv\_tsMLI} = 1.536 \text{ watt}$$

$$W_{6vv\_tsMyl} = 38.821 \text{ watt}$$

$$Q_{con\_vv\_ts} = 67.073 \text{ watt}$$

$$Q_{mag\_VV} = 0 \text{ watt}$$

#### To the absorber - MLI, good vacuum:

$$Q_{extremity\_abs} = 8.507 \text{ watt}$$

$$Q_{cond\_abs} = 0.355 \text{ watt}$$

$$Q_{condts\_abs} = 6.03 \text{ watt}$$

$$W_{6ts\_absMyl} = 0.218 \text{ watt}$$